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Greener energy: Issues and challenges for Pakistan—Biomass energy prospective

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ABSTRACT

Diversification of fuel sources is imperative to address the energy security, climate change, and sustainable development issues; therefore, it is essential to address the energy crisis through the extensive utilization of abundant renewable energy resources, such as biomass energy, solar energy, wind energy and geothermal energy. Improving energy services for poor households in developing countries remains one of the most pressing challenges facing the development community. Earlier studies suggest in South Asia the households are likely to follow the energy ladder comprising fuels like dung, crop residue, firewood, kerosene, gobar gas, LPG, and electricity for cooking purposes. Evidence suggests that while it is possible to observe such transition in urban and semi-urban areas, the change is very slow in rural areas. In rural Pakistan, the access to commercial energy resources is limited, the majority of the households still heavily rely on traditional methods of using wood, animal waste and crop waste for domestic fuel needs. Efficiencies of use are very low and most of the potential is wasted because of non-scientific conventional technologies. Consequently there is an obligatory need to develop modern bio-energy technologies since renewable resources may serve to supplement the long-term energy needs of Pakistan to a significant level. Though the bio-resource base of Pakistan is substantial, its contribution to useful energy is low. In this paper we called attention to issues and challenges in biomass utilization for energy in Pakistan in context of sustainable development. This paper has identified areas in Pakistan where there is considerable scope to modernize biomass energy production delivery systems to provide varied energy carriers such as electricity, industrial and domestic fuel and gases. Barriers are examined over the whole biomass energy spectrum and policy issue and institutional roles and responsibilities are discussed.

Contents

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1. Introduction and background

Through the different stages of development, humankind has experimented with various sources of energy ranging from wood, coal, oil and petroleum to nuclear power. In recent years, public and political sensitivities to environmental issues and energy security have led to the promotion of renewable energy resources. Biomass is one such resource that could play a substantial role in a more diverse and sustainable energy mix.

Energy plays a pivotal role in socio-economic development by raising standard of living. Biomass has been used as an energy source for thousands of years by the humankind. Statistical data from the International Energy Agency [1] show that conventional energy resources, such as oil, are still the most important sources of energy followed by coal and gas, accounting for approximately 80% of Total Primary Energy Supply (TPES). The next important contributor is Combustible Renewable Energy (CRE), which contributes around 10% of the world's TPES share. CRE, or traditional biomass energy, constitutes 80% of the total renewable energy consumed mainly in developing countries while other forms of modern renewable energy, such as hydro, geothermal, solar and wind power are consumed mainly in developed countries [1].

Diversification of fuel sources is imperative to address the energy security, climate change, and sustainable development issues. Furthermore, too much reliance on the non-renewable sources to generate power is also unviable in the long run. Thus, it is essential to address the energy crisis through the extensive utilization of abundant renewable energy resources, such as biomass energy, solar energy, wind energy and geothermal energy [2]. The potential of biomass to help to meet the world energy demand has been widely recognized. The reduction on the imported forms of energy and conservation of limited supply of fossil fuels depends upon the utilization of all other indigenous fuel energy sources [3].

Presently, renewable energy worldwide is still dominated by the "old" renewable such as hydropower and traditional biomass that supply 6 and 9% of global primary energy demand, respectively. Only around 2% of the world's primary energy is currently provided by "new" renewable sources such as wind, photovoltaic and mini- and micro-hydro [2]. In South Asia the households are likely to follow the energy ladder comprising fuels like dung, crop residue, firewood, kerosene, gobar gas, LPG, and electricity for cooking purposes. Evidence suggests that while it is possible to observe such transition in urban and semi-urban areas, the change is very slow in rural areas [4]. Improving energy services for poor households in developing countries remains one of the most pressing challenges facing the development community. The dependence of these households on traditional forms of energy leads to significant health impacts as well as other major dis-benefits, yet there has been little progress in meeting this challenge. One major drawback of biofuel use is that these fuels are used in traditional stoves and furnaces, which are inherently inefficient. It is well known that conventional mud stoves operate with thermal efficiencies of the order of 10% or less [5,6]. A number of inherent disadvantages of the traditional fuels are widely reported, and these include arduous and time-consuming nature of fuel collection, difficult to control combustion process, and inefficient heat exchange [7]. Even more important is the serious health threat that traditional fuels pose for the persons involved in cooking. Cooking with bio fuels on an open fire within a confined space can lead to acute respiratory problems, particularly for women and children [4,7].

Pakistan is situated in the south Asian region covering a total land area of 888,0000 km^2. It has a population of 173.51 million with annual growth rate of 2.05%, it is expected that Pakistan will become the fourth largest nation on earth in population terms by 2050 (Economic Survey of Pakistan 2010). The draft population policy 2009–2010 envisages to reduce fertility level from 3.56 (2009) to 3.1 births per woman by the year 2015. With a median age of around 20 years, Pakistan is also a "young" country. It is estimated that there are currently approximately 104 million Pakistanis below the age of 30 years.

Pakistan is agricultural country. Nearly 62% of the country's population resides in rural areas, and is directly or indirectly linked with agriculture for their livelihood. Pakistan has very low forest cover; about 5.17% of total land area is covered by forests, 5% of which is protected. In order to reduce pressure on natural forests, national forest policy call for promotion of alternate energy resources including energy plantations, micro-hydropower generation, bio-gas, solar and wind energy, liquid petroleum gas (LPG) and natural gas shall be promoted in critical mountain ecosystems. Fuel efficient cooking stoves and energy efficient houses shall be promoted throughout the country.

Rural electrification has always been a central objective for power sector reforms in Pakistan. But there is no firm government policy for the development of decentralized power supply. With a young and growing population, low per capita electricity consumption, rapid urbanization and strong economic growth, Pakistan for nearly two decades has been one of the fastest growing power markets in the world. However since five years, the economic progress has been greatly hampered by acute energy scarcity [8]. In order to address issues pertaining to energy security, climate change and sustainable development, Pakistan being falling in the same scenario discussed earlier, needs to adopt clean and renewable energy mix. Utilization of biomass is a very attractive energy resource since biomass uses local feedstock and labour. Traditionally, biomass has been utilized through direct combustion, and this process is still widely used in many parts of the world [9]. Sahir and Qureshi [10] after assessing new and renewable energy resources potentials of Pakistan concluded that renewable resources may serve to supplement the long-term energy needs of Pakistan to a significant level. More than 62% of the population in Pakistan lives in the rural areas, where access to commercial energy resources is limited and traditional methods of using wood, animal waste and crop waste for domestic fuel needs are the only choice. Efficiencies of use are very low and most of the potential is wasted because of non-scientific conventional technologies. Chaudhry et al. [11] presented a review accentuating the importance and challenges of new era technologies in Pakistan, concluding that the renewable energy sources like wind energy, solar energy, geothermal energy, ocean energy, biomass energy and fuel cell technology can be used to overcome energy shortage in Pakistan. Renewable energy

sources and technologies have the potential to provide solutions to the long-standing energy problems being faced by the developing countries. The expansion of existing energy resources and exploration of new sources is an important exercise to be considered in order to sustain their development initiatives. Although the bio-resource base of Pakistan is substantial but its contribution to useful energy is relatively low. An indirect consequence of the low efficiency energy use is that the carbon emissions would be high. Factors such as collection, processing, low end use efficiency of conventional devices and insufficient maturity of present biomass energy technologies are major barriers for utilizing the available bio-resources more efficiently and on a sustainable basis. Utilization of a basket of energy technologies, rather than a single technology (as is the current norm in most government programs) to deliver energy and economic services in rural areas seems to hold the key for successful commercialization and mainstreaming of biomass energy technologies [5] as providing clean and affordable energy reliably for poor households in developing countries is an important prerequisite in the fight against poverty [7,12]. In this paper we called attention to issues and challenges in utilization biomass energy in Pakistan in context of sustainable development.

2. The Pakistan scenario

Pakistan is today beset with serious energy supply difficulties due to rapid increase in demand, poor endowment of energy resources, high costs of energy imports, expanding industrialization and high population growth rate. The heavy population growth has resulted in increased demand for housing and electricity. The rural sector, which comprises 62% of the total population, is dependent on the use of noncommercial energy resources. The infrastructure of industry, agriculture, transport, roads and the construction of buildings needs to be improved and requires a supply of energy to accelerate the development process.

Together with environmental implications, agriculture has emerged as focal area of national economic growth in Pakistan and has the potential for addressing unemployment. Due its higher employment elasticity than industry, agriculture sector has emerged as the largest sector of Pakistan's economy and needs more assured supplies of energy and better energy inputs to attain self-sufficiency in food and to generate more foreign earnings through exports. The rural population has only marginal access to electricity for lighting, water heating and cooking. Poor energy supplies also constrain productivity growth in the agricultural sector.

The level of primary energy consumption in Pakistan is very low. The present per capita commercial energy consumption is around 0.25 Tons of Oil Equivalent (TOE) and per capita electricity consumption is 350 kWh. This corresponds to about half the average for developing countries, one-seventh of the world average and one-twentieth of the average for the industrialized developed countries [8].

Traditional fuels like firewood, dung and crop residues currently contribute a major share in meeting the everyday energy requirements of rural and low-income urban households in Pakistan. In the rural areas in Pakistan, foods are cooked in the traditional cooking stove where biomass fuels are mainly used as energy because of the unavailability of natural gas (Table 1). Larson and Kartha [13] have referred biomass fuels as "the poor woman's oil", since women (and children) in rural areas must devote a considerable amount of time collecting daily fuel wood needs and suffer the brunt of indoor air pollution caused by direct combustion of biomass for cooking and heating. The direct use of biomass by combustion for domestic cooking and heating ranks it at the bottom of the ladder of preferred energy carriers.

In rural Pakistan, the majority of the households rely on biomass fuels mainly due to the unavailability of better alternatives. An average biomass using household consumes 2325 kg of firewood or 1480 kg of dung or 1160 kg of crop residues per annum [14]. According to WHO estimates, the annual number of deaths in Pakistan attributed to solid fuels is 70,700 while the percentage of national burden of disease attributed to solid fuel use is 4.6%, as compared to less than 1% seen in the developed world [15].

Table 1
Cooking fuel used in Pakistan.

Cooking fuel	Urban areas (%)	Rural areas (%)
Wood	19.55	68.71
Oil/natural gas	77.84	7.41
Electricity	0.05	0.07
Others[a]	2.56	23.81

[a] "Other" consists of dung cake and any material used as fuel for cooking other than electricity, gas/oil, and wood/charcoal.

Defining precisely, the organic matter derived from biological organisms (plants and animals) is called biomass. Bio-energy can be defined as energy obtained from biological and renewable sources (biomass); bio-energy may be derived in the form of heat or transformed into electricity for distribution. Biomass also can be transformed into biofuels, which are portable feedstock for use in the generation of bio-energy. Biofuels are defined as feedstock intended for the production of bio-energy, produced directly or indirectly from biomass. Biofuels can be in solid form (fuel wood, charcoal, wood pellets, briquettes, etc.) or liquid (bioethanol, biodiesel).

With the emerging development on bio-energy today using more modern technology, biomass energy can be divided into traditional biomass and modern bio-energy. Traditional biomass is the main source of energy used in developing countries primarily for cooking and space heating at the household level, mostly using three-stone stoves, or in some areas improved cooking stoves. This source of energy is in the form of wood-fuel (including fuel wood and charcoal), crop residues and animal dung and is often collected by women and children on a daily basis. In some areas traditional biomass is also traded within villages and among villages or with nearer townships. Another characteristic of traditional biomass is using traditional technology with low efficiency due to poor design, uncontrolled and open burning, which have important health implications. Modern bio-energy is used mostly for the generation of electricity or transportation. Liquid biofuels for transportation such as ethanol and biodiesel are examples of the emerging energy alternatives. More than 62% of the population in Pakistan lives in the rural areas, where access to commercial energy resources is limited and traditional methods of using wood, animal waste and crop waste for domestic fuel needs are the only choice. Efficiencies of use are very low and most of the potential is wasted because of non-scientific conventional technologies. Consequently there is an obligatory need to develop modern bio-energy technologies since renewable resources may serve to supplement the long-term energy needs of Pakistan to a significant level.

3. Biomass in Pakistan: resource base and environmental concerns

According to Economic Survey of Pakistan 2009–2010 during the year 2009–2010 forests have provided 263 thousand cubic meters of firewood which has been used for cooking in rural areas [8]. Country's existing forest resources are under pressure to meet the fuel wood and timber needs of rising population and wood based industries including housing, sports, matches, boat making and furniture industries. ADB [16] has attributed the problem of deforestation in Pakistan largely to excessive fuel wood collection.

Over the past several years, the forest sector has contracted, underscoring the scale of the environment challenge facing a country that already has among the highest rates of deforestation in the world. The economic rationale behind the over harvesting of forest rests with the scarcity of fuel alternatives at a comparable or lower price. Lack of alternate fuel wood aggravated the problem. Alternatives, such as kerosene oil or natural gas, are either not available or too expensive for the local communities. Given that only 5.3% of country's total land area is under forest ranking it under Low Forest Cover Countries, in MTDF (2005–2010) Pakistan is committed to increase forest cover from existing 5.2% to 5.7% by the year 2011 and 6% by the year 2015 [17]. An increase of 1% implies that an additional 1.051 million hectares area has to be brought under forest cover by 2015.

Another bio-resource in Pakistan is cattle dung. There are approximately 62 million of animals (buffalo, cattle, camel, horses, asses and mules) with annual growth rate of 8% in the country [18]. This means that the wet dung would be available as a sustainable resource. On average, the daily dung dropping of a medium size animal is estimated at 10 kg. This would yield a total of 620 million kg dung per day which was either disposed of in fields or used for domestic energy requirements. According to Ghaffar [19], 25% of total animal waste is lost during collection and 50% is used for fertilizer applications in the fields. One kilogram of animal dung (dry mass) produces 0.19 m^3 of biogas at 15+ °C, and the rate of gas production becomes double at 27 °C [20]. Based on these results 20 kg (wet mass) of dung can produce 1 m^3 gas/day [19] at 25.8 °C (the annual mean temperature of Pakistan), therefore the total biogas production from all collected animal dung will be around 23.25 million m^3/day. From the Indian experience [21], on average 0.227 m^3/person/day of biogas (55% methane) is required for cooking, 0.127 m^3 for a 100 candle-power lamp for lighting, and 0.57 m^3/h for running a generator of 1 kW capacity. Given that Pakistan and India have same climate and social, culture and traditions we can safely assume the same level of consumption in Pakistan as well. Therefore 23.25 million m^3/day of biogas could meet the cooking needs of around 100 million people depending upon consumption rate.

Agriculture residues are another potential biomass feedstock available in Pakistan for energy conversion. The term agricultural residue is used to describe all the organic materials which are produced as the by-products from harvesting and processing of agricultural crops. These residues are further categorized into primary residues and secondary residues. Agricultural residues, which are generated in the field at the time of harvest, are defined as primary or field based residues (e.g. rice straw and sugar cane tops), whereas those co-produced during processing are called secondary or processing based residues (e.g. rice husk and bagasse). Availability of primary residues for energy application is usually low since collection is difficult and they have other uses as fertilizer, animal feed, etc. However secondary residues are usually available in relatively large quantities at the processing site and may be used as captive energy source for the same processing plant involving no or little transportation and handling cost. Table 2 lists the potential crops generating residues and their available quantity in Pakistan.

Though the bio-resource base of Pakistan is substantial, its contribution to useful energy is low. An indirect consequence of the low energy use efficiency is that the carbon emissions would be high. One major drawback of present bio-energy resource use is that these fuels are used in traditional methods which are inherently inefficient. The most common method of cooking throughout rural areas is the open hearth or three-stone fire, which transfers around 5–15% of the fuel energy to the cooking pot. By comparison, kerosene and LPG stoves provide efficiencies of around 40% and 50% [7,23].

4. Supply and distribution system of wood fuels in Pakistan

Wood fuels are an important source of energy for in Pakistan, its supply and distribution system are discussed here. The distribution system of wood fuels differs in rural and urban areas. In rural areas people mostly depend upon the wood fuel and other biomass collected locally. The urban people get their wood fuel supplies mainly from the traded sources. However, the size, nature and sources of supply of wood fuel and other biomass differ with the objectives of collection, namely, household use or trade.

4.1. For household use

People in rural areas collect wood fuel and other biomass almost freely from the surrounding supply sources that may be public forests, community forests, wastelands or private farmlands. From the public/community forests and wastelands, people mostly collect wood fuel and other biomass under some recorded or traditional rights. Under these rights, the people can remove the dead and fallen trees with the least use of cutting tools to meet their bonafide domestic needs but not for sale. During collection of wood fuel, however, the people do not observe the restrictions as laid in the legal definition of rights. In addition to collection of dead and fallen trees, they cut or heavily lop standing trees. Wood fuel and other forest-based biomass comprise branches, poles, split wood, cones, bark, leaves and needles. It may also include shrubs, cut or uprooted. Tree stumps felled earlier for timber production also serve as a source of wood fuel for the local population. Logging residues of all kinds (tops, branches, broken pieces, chips, bark, etc.) in the mountain forests, irrigated plantations and riverain forests are of low commercial value and are freely collected by the local people. Biomass fuel supply from farmlands comprises various tree parts and a variety of agriculture residues and animal waste. Landlord farmers meet their fuel need from their own farms, while tenant farmers collect it free. Landless village people collect agriculture residues freely as gesture of good will from the landlord farmers or purchase it.

4.2. For commercial purposes

Traded wood fuel in Pakistan comes from various sources. Important ones are farmlands, public forests and wastelands. The main sources of traded wood fuel supplies in the country (listed in Table 3) are from farmlands in the Punjab and Sindh. Government forests (irrigated forest plantations and riverain forests) are the major suppliers of traded wood fuel in the public sector. Their contribution in the overall wood fuel needs of the country is, however, insignificant because of the low forest area under their control. The HESS survey shows that 40% of sampled households in Pakistan collect fuel wood from private lands and another 32%, from own lands. Only 13% are collecting from state forest lands.

4.3. Wood fuel transportation

Wood fuel is a bulky material in comparison to its production and utilization value. Therefore, transportation costs make up a good part of its marketing price. General means of transport are head-loads or pack animals. Carriage by head-loads woks well up to a distance of 3 km, but depend upon the age and sex of the collector, size of the load, season of the year and nature of the country. The fuel collected by head loads goes almost entirely in the direct use of the collectors. A part of the wood fuel extracted and transported by pack animals (donkeys, mules and camels) may go in informal marketing for local use.

Bullock/camel carts are used in the plain country of Punjab and Sindh province for short distance transportation. Their use is, how-

Table 2
Production of different crops and their respective residue availability in Pakistan [8,22].

Name of the crop	Annual production (thousand M T) [8]	Type of residue	Crop to residue ratio (residue/kg crop) [22]	Total available residue (thousand M T)
Rice	6883	Husks	0.2	1376.6
		Stalks	1.5	10,324.5
		Straw	1.5	10,324.5
Cotton	3000	Boll shell	1.1	3300
		Husk	1.1	3300
		Stalks	3.8[a]	11,802.8
Wheat	23,864	Pod	0.3	7159.2
		Stalks	1.5	35,796
Sugarcane	49,373	Bagasse	0.33	16,293.09
		Top and leaves	0.05	2715.515
Maize	296	Cobs	0.3	88.8
		Stalks	2	592
Bajra	470	Cobs	0.33	151.183
		Husks	0.3	141
		Stalks	2	940
Barley	82	Stalks	1.3	106.6
Dry chilly	187.7	Stalks	1.5	281.55

[a] Tons/hectare.

Table 3
Sources of collected firewood in Pakistan (%) [24].

	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Pakistan
Own land	38.7	14.1	39.9	8.4	31.7
Other private land	40.1	55.3	24.4	9.9	40.3
Common land	9.9	9	14.7	48.1	12.1
State forest land	8.4	17.8	17.1	26.3	12.6
Other (waste wood, etc.)	2.9	3.8	3.9	7.5	3.3
Total	100	100	100	100	100

ever, fast replaced by tractor-trolley: certainly a faster means of transport. In mechanical transport, different types of vehicles are employed. Trucks are used for long distance transport of wood fuel. There are about 216,043 trucks in the country. Most of these are also employed in the transportation of a wide variety of items in addition to wood fuel. In large rivers in plains, wood fuel is transported with boats over long distances. In hilly regions, the wood fuel is transported in small streams in the shape of billets and splits. Transport by floating is only suited for thick wood fuel. In Sindh province, wood fuel transportation by boats is carried out over as long distances as 160 km. About 450 boats are employed for this purpose. Of these, 250 are big boats and 200 small ones. Big boats carry a wood fuel load of 40–45 tons and small boats carrying 2–8 tons.

The sale prices of wood producers vary on the basis of tree type and quantity sold. The prices for all the sales ranged from Rs. 125 to 1000/ton during 1991–1992, with an average price of about Rs. 450/ton. Babul (*Acacia nilotica*) prices were the lowest, fetching about Rs. 350/ton, while assorted pieces of other species fetched roughly 50% higher prices; Rs. 530/ton. Mostly the provinces are self sufficient in wood fuel supplies except Balochistan, where wood fuel is drawn mostly from the neighboring Sindh province.

5. Traditional biomass categorization

Biomass can be categorized broadly as woody, non-woody and animal wastes. Woody biomass comprises forests, agro-industrial plantations, bush trees, urban trees and farm trees. Woody biomass is generally a high-valued commodity and has diverse uses such as timber, raw material for pulp and paper, pencil and matchstick industries and cooking fuel. Non-woody biomass comprises crop residues like straw, leaves and plant stems, processing residues like saw dust, bagasse, nutshells and husks and domestic wastes (food, rubbish and sewage). Animal waste constitutes the waste from animal husbandry [25].

Animal dung is a potentially large biomass resource and dried dung has the same energy content as wood. When burned for heat, the efficiency is only about 10%. About 150 million tons (dry) of cow dung are used as fuel each year across the globe [14]. Traditional fuels like firewood, dung and crop residues currently contribute a major share in meeting the everyday energy requirements of rural and low-income urban households in Pakistan. Still 62% population is living in rural areas. As a result, this component is much higher in rural areas with dominant use of firewood for cooking and heating purposes. When scarce, firewood is substituted by crop residues and animal dung [8]. Low-income families and people living in rural areas of the country heavily depend on traditional biomass, i.e., fuel-wood, charcoal, animal dung, etc., to meet their daily energy needs. An estimated 30% of total energy consumed in the Pakistan comes from traditional biomass fuels [26]. According to the Pakistan Social & Living Standards Measurement Survey 2008–2009, about 53.29% of the country's total households and 68.71% of rural households depend on wood and charcoal for cooking.

5.1. Traditional biomass energy

Traditional biomass energy is usually defined as fuel wood and charcoal, agricultural residues, and animal dung. Because agriculture is the dominant economic activity in rural areas where most users of traditional biomass fuels reside, much "traditional" energy is associated with agriculture—in essence, it recycles agricultural byproducts (animal dung and crop residues, especially) to useful energy for the household. Where available, non-agricultural sources of energy—such as forests—also con-

Table 4
Comparison of efficiency of common fuels [28].

Fuel type	Price (Rs/kg)	Colorific value (MJ/kg)	End-use efficiency (%)	MJ of useful heat per Re. spent	Energy Cost (Rs/MJ)
Wood	2.60	15	2.25	0.87	1.49
Kerosene oil	16.34	45.6	18.24	1.12	0.89
LPG	27.0	47.8	31.07	1.15	0.86
Dung	0.95	12	1.80	1.89	0.52

Table 5
Efficiencies of selected stoves using charcoal as fuel [29].

Name of cookstoves	Efficiencies of selected stoves using charcoal as fuel Efficiency (%)
Cambodian traditional	14.5
Thai-bucket cookstove	16.2
Chinese traditional	12.5
QB Phil. charcoal=_rewood	27.0
Phil. charcoal=wood	21.5
Lao improved	16.5
Vietnamese improved	25.0
Malaysian improved	18.0
Bang Sue stove	18.2

tribute to energy budgets, mainly in the form of cut wood and charcoal.

The fuels and devices available to people living in poverty are typically less efficient, more hazardous to users and more damaging to the environment than those enjoyed by the better off. The use of traditional fuels has a negative impact on the health of members of the household, especially women and children, when burned indoors without either an efficient stove to control the generation of smoke or a chimney-fitted stove to vent the smoke outside [27]. The amount of energy required for cooking varies with the type of food, the fuel and stove used and the specific cooking practices of a household. Comparison of efficiency of common fuels is given in Table 4 while efficiencies of commonly employed charcoal and wood-stoves are given in Tables 5 and 6.

Traditional cookstoves cause indoor concentrations of important pollutants, such as small particles less than 10 μm (1 μm = 10^{-6} m) in diameter, known as PM10, carbon monoxide, benzene and formaldehyde, to be excessive compared to health-based standards or even to other common thermal applications. Such exposures are linked to acute respiratory infections, chronic obstructive lung diseases, low birth weights, lung cancer and eye problems, primarily among women and children [30]. Similarly, kerosene-based household lamps are inefficient, expensive, and a source of health and fire hazards. These lamps produce unhealthy fumes which in poorly ventilated homes pose serious health hazards such as respiratory and eye problems; yet, lighting using kerosene can be twice as expensive as and up to 19 times less efficient per lumen of output than fluorescent lights using electricity as the energy carrier [31]. Moreover, inefficient lighting services in the home and in public areas are directly related to poor safety and personal security.

There are two responses to this problem: improved devices for using biomass fuels, or the use of alternative fuels and devices for providing these energy services. An improved wood-burning cookstove improves efficiency by controlling the flow of air into the combustion process and by improving heat transfer from the fuel and hot combustion gases to the cookstove. Some improved stoves also have a chimney to remove the combustion products from the kitchen.

Due to the increased population growth and repeated fragmentation of the village forests, the biomass fuel cycle in the rural floodplain areas of Pakistan is probably unsustainable. Rather, it leads to increased collection of fuel wood from village forests and consequent deforestation. The design of the traditional cooking stove and the type of fuel used are important determinants of fuel use efficiency, which is related to the emission of greenhouse gases.

In one of the improved stove programs in Pakistan, a Lahore-based NGO with funding from UNDP has developed and introduced a fuel-efficient cookstove to relieve pressure on fuel-wood resources in the Chhanga Manga forest and improve the health and economic prospects of village women. The stoves are made of mud and straw by the women who use them. About 11,500 stoves have been installed, serving over 90,000 people [32]. They consume much less than half the fuel-wood consumed by a traditional stove. These fuel-efficient stoves all have chimneys which are made from recycled old steel bins or from mud to save on cost. The steel chimney is fabricated from sheet steel or old tin cans by a local blacksmith. A short steel rod is used to reinforce the entrance to the combustion chamber, and steel is used for chimney dampers and fire-box gates. The stoves are designed so that two pots can be used at the same time, with a cover to go on a pot-hole when it is not in use. The steel chimney is a little expensive while the manufacture of mud chimneys is time-consuming [32]. Pakistan Council of Renewable Energy Technologies (PCRET), a unit of the Ministry of Science and Technology, has also developed five different models of efficient cookstoves for use in different parts of the country and disseminated 70,000 such stoves [33]. However, a large section of poor people still use traditional inefficient stoves for cooking. A study shows that the urban poor are in general more likely to benefit from improved stoves than the rural poor for a number of reasons listed below [34]. The urban poor are more likely to be using stoves of some sort in the first place, rather than an open fire.

1. The urban poor are more likely to spend money rather than time on acquiring fuel. The urban poor are also more likely to spend money on buying stoves, rather than constructing their own.
2. The urban poor are more likely to have better access to credit than their rural counterparts, so they may be in a better position to spread initial capital costs of buying a new stove.

The production, dissemination and marketing of improved stoves are also easier in urban areas due to the existence of more specialized skills, greater population density, and better communications and marketing infrastructure.

5.2. Biogas

It is reported that presently there are 5357 biogas units installed in the country. The unit sizes are 3–15 m^3/day. The estimated countrywide biogas potential is 12–16 million m^3/day [35]. There are good prospects for using biogas energy in rural areas of Pakistan through a network of community biogas plants. The amount of dung-waste is enough to produce about 12 million cubic meters of biogas per day that could suffice to meet energy requirement of 28 million rural people, in addition to production of 21 million tons of bio-fertilizer per year.

Directorate General of New and Renewable Resources (DGNRER) under the Ministry of Petroleum and Natural Resources started a comprehensive biogas scheme in 1974 and until 1987 commissioned 4137 biogas units throughout the country. The units

Table 6
Efficiencies of wood-fired stoves [29].

Name of cookstoves	Efficiency (%)	Name of cookstoves	Efficiency (%)
Cambodian traditional	11.0	Phil. charcoal=wood	12.0
Lao traditional	14.3	Nepal one-pot metal	13
Vietnamese traditional	15	Nepalese two-pot ceramic	13.0
Nepalese one-pot ceramic	10.5	Nepalese two-pot metallic	15.0
Thai-bucket cookstove	14	Lao improved cookstoves	18.4
Roi-et clay	11.2	Viet. improved cookstove	17.5
Roi-et cement	11.4	Indian "Harsha" cookstove	25.2
RTFD improved wood=char	15.0	Saengpen, narn char=wood clay	20.2
Rungsit stove	12.0	Saengpen, nam char wood cement	17.5
Chinese traditional	12.2	Bang Sue stove	18.2
Malaysian traditional	9.5	Bang Sue modified	21.7
QB Phil. charcoal=wood	23.0	Malaysian improved	19.7

were designed to provide 3000 and 5000 cubic feet of biogas per day for cooking and lighting purposes [36]. The program was developed in three phases. In Phase I, DGNRER installed 100 demonstration units of Chinese fixed-doom design on grant-basis. During Phase II, the cost of the biogas plant was shared between the beneficiaries and the government and in Phase III, government withdrew the financial support; however, free of cost technical support remained but not on persistent basis. This program practically failed due to the following reasons [36]:

- withdrawal of government financial support;
- lack of technical training to the communities;
- lack of awareness raising and experience sharing;
- high cost of the technology;
- lack of motivation;
- inadequate demonstration;
- inadequate communities' (beneficiaries') participation.

Parallel to DGNRER, the Pakistan Council of Appropriate Technology (PCAT) was also working for the development of renewable energy technologies under the Ministry of Science and Technology, which was curtailed to R&D for the promotion of biogas technology in the country and became focal point for the biogas-related activities. In 2001, PCAT was merged with National Institute of Silicon Technology to create Pakistan Council of Renewable Energy Technologies (PCRET) under the same ministry. PCRET has initiated a comprehensive package for the development and dissemination of biogas plants and other appropriate sustainable technologies into the lives of the people in rural areas of the country [36].

Recently, PCRET has installed 1200 biogas plants throughout Pakistan on cost-sharing basis, where 50% cost is to be borne by the beneficiary [37]. Apart from these, three community size biogas plants have been installed in rural areas of Islamabad, which are meeting domestic fuel needs of 20 houses. A 1000 m^3 biogas plant is being designed for installation near Cattle Colony, Karachi [37]. Biogas provides clean and smoke free energy unlike firewood. Thus installation of biogas helps reducing indoor air pollution and hence reduces the incidence respiratory diseases. Almost all households reported that biogas has helped improving the health [38]. In the light of above discussion, Sahir and Qureshi [10] suggested that instead of focusing on the small scale family and community units, the huge assessed potential of biomass should be utilized to develop large-scale biogas plants operating on crop and animal wastes in the rural areas and on street waste in the urban areas. Experience from the success of such large-scale biogas pilot projects in Japan can help the planners in this regard.

AEDB is working on biogas project at Landhi Cattle Colony, Karachi, and pilot phase of the project will be funded by New Zealand Aid (NZAID). Waste from 400,000 cattle in the area would be utilized to generate electricity through biogas plants/generators and high grade organic fertilizer. The pilot phase of the project will generate 250 kW of electricity through biogas whereas generation capacity will be extended to 30 MW along with production of 1500 tons of organic fertilizer per day. Another biogas power generating plant with a capacity of 8.25 MW is under construction in Shakarganj Mill with the technical assistance of AEDB.

Average monthly income of household in Pakistan is $92. For rural household, the percentage of monthly consumption expenditure on fuel and lighting is 8.09% compared to 6.82% in urban. Due to their lack of access to modern energy services, about 86% of rural households and 32% of urban households use biomass fuels for cooking purposes [16]. Most urban households, however, have switched from biomass fuels to cleaner and more convenient sources of energy. There is growing demand for connections to natural gas supplies due to the subsidized rates available to smaller domestic user. Nonetheless, most rural households continue to rely on biomass fuels. When food is cooked in closed spaces in winter, children become sharply vulnerable to acute respiratory infections, particularly in mountain and hill areas. Simple low-cost solutions such as the use of hoods and vents can markedly reduce smoke inhalation from biomass fuel-based cooking stoves. Although projects promoting these innovations have been implemented to a small degree, they have not been incorporated in sustained rural development programs.

5.3. *Fuel-efficient stoves*

Policies to widely promote and disseminate improved rural energy technology have been undertaken in China since the early 1980s [39]. The most successful components of these policies are the extensive dissemination of fuel-saving improved biomass stoves, mini hydropower plants, and biogas digesters. China's dissemination of improved biomass stoves (mainly designed for wood or crop residues) remains the most successful such program worldwide with estimates of over 99 million installed between 1983 and 1988 [39]. The dissemination of fuel-saving improved stoves has been reported to be the most cost-effective measure in rural energy conservation undertaken in China [39]. Improved biomass stoves are intermediate steps along the "energy ladder" toward eventual provision of clean liquid and gaseous fuels and expanded use of electricity for all households. Although widespread adoption of clean fuels is likely to be decades in the future, given the large variety of economic and agro-climatic conditions in China, there are undoubtedly many communities where policies to promote movement to cleaner fuels are more cost-effective today than improved biomass stoves [40].

Wood, crop residues, dung and grass are used in about 60% of the households in the country as energy sources for cooking and heating. Development of fuel-efficient cookstoves is a modest effort to help conserve biomass energy at domestic level. Improvements in the efficiency of the conventional cookstoves have reduced the con-

sumption of wood, thus mitigating environmental pollution, saving domestic expenditure and slowing down deforestation.

Fuel Efficient Cooking Technology project was funded by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) and implemented throughout the country. Following encouraging results, another program (Fuel Saving Technology) was initiated by the government. The program, providing incentives to NGOs and community-based organizations, resulted in NGOs and private sector improving the quality and efficiency of cookstoves to a level that they are now exporting cookstoves to Afghanistan and Central Asian States [41,42]. Fifty molds of fuel-efficient stoves were prepared and provided to the field units of National Rural Support Programme (NRSP). The communities were trained for their use. The communities are using the stove molds for constructing fuel-efficient stoves. Some of the females have started it as an enterprise and are selling the stoves [41]. PCRET has so far installed 60,000 energy-conserving, improved cooking stoves all over the country, which are 12–28% efficient [35,43].

6. Plans and strategies to promote biomass use in Pakistan

Reduction of workload for women and children for the collection of firewood for cooking is one of the most significant benefits of biogas. Given the economic status of rural households, the family sized biogas is still costly for poor households and these households.

There is need of more research and development (R&D) so that the cost can be reduced and the technology is made affordable for the poor households. Moreover, cost could be one reason but, there are other factors that influence the demand such as awareness and availability of loan. Thus, factors that affect the demand need to be identified so that the demand for the technology can be increased. Biogas in Nepal is focused mainly in family sized plants. It could potentially be applied to communities and for municipal waste recycling. Until now, with some exceptions, cattle dung has been used primarily as an input for the biogas. There has been limited use of biogas for kitchen waste, municipal waste and slaughter house waste, but not on a large scale. Use of other alternative biodegradable feedstocks such as municipal waste should be encouraged and promoted. This could be an effective option for disposing and recycling municipal waste. Bio-slurry has proved to be an effective fertilizer but there are some health risks associated with its use. More R&D is required for the proper storage and application of bio-slurry to minimize the health risks.

The efficiency of conversion of animal residues could be raised to 60% by producing biogas through anaerobic digestion. Biogas systems offer multiple benefits. For cooking and other household thermal tasks, it is simple and reasonably efficient to use the gas directly in conventional low-pressure gas burners. Biogas can provide lighting when used in mantle lamps. The digester effluent adds economic value by providing valuable fertilizer. It leads to environmental protection as well as improving sanitary conditions in rural areas. Biogas plants are widely in operation in China, India, Sudan, Taiwan, etc. [25,44,45].

The government should plan and develop biogas projects to introduce biogas technology for cooking and lighting purposes in the rural sector. In this respect, high technology digesters, which can use wide variety of feedstocks and generate more gas [46] could be adopted and installed in the country.

The targets set in National Development Vision—2004 and PCRET Vision—2020 are as follows [35]:

- provision of 250 m^3/day biogas plants for 50,000 families;
- generation of 500 MW electric power using municipal/agriculture solid waste;

Table 7
Selections of technologies for conversion of biomass energy into modernized energy carriers, along with possible energy services [13].

Technology	Scale	Energy services provided
Biogas	Small	Electricity (local pumping, milling, lighting, communications, refrigeration, etc. and possible distribution via utility grid)
Producer gas	Small to medium	Cooking and heating
Ethanol	Medium to large	Vehicle transportation, cooking
Steam turbine	Medium to large	Electricity (for industrial processing and grid distribution), industrial process heat

Three projects with a total budget of Rs. 37.77 million were approved by the government for implementation during 2002–2005 periods. They covered the areas of fuel saving technology, promotion of biogas and dissemination of biogas plants for meeting energy requirements.

6.1. The potential for modernized bioenergy

Hall [47] acknowledged there is a growing recognition in the world that the use of biomass energy in larger commercial systems based on sustainable, already accumulated resources and residues can help improve natural resource management. If bioenergy were modernized (i.e., the application of advanced technology to the process of converting raw biomass into modern, easy-to-use energy carriers such as electricity, liquid or gaseous fuels, or processed solid fuels), much more useful energy could be extracted from biomass than at present, even without increasing primary bioenergy supplies. Biomass energy has the potential to be “modernized” worldwide, i.e., produced and used efficiently and cost competitively, generally in the more convenient forms of gases, liquids, or electricity. Table 7 lists a few of the technologies which can convert solid biomass into clean, convenient energy carriers. Most of these technologies are commercially available today. If widely implemented in combination with sustainable supply of biomass feedstocks, such technologies would enable biomass energy to play a much more significant role in the future than it does today.

6.1.1. Household applications

Most households in developing countries that use biomass fuels today do so largely because it is available at low (or zero) financial cost or because they lack access to or cannot afford higher quality fuels. Improvements in wood and charcoal stoves over the past couple of decades have allowed households to cook with biomass more efficiently, more cleanly and with greater convenience. Still, as incomes rise, households invariably choose to consume more of higher quality fuels such as kerosene, liquified petroleum gas, natural gas, and electricity [48,49]. This shift is associated with the quality of the energy carrier utilized rather than with the primary energy source itself. Gaseous cooking fuels can be used far more efficiently and conveniently than solid fuels, while also emitting far fewer toxic pollutants. Thus, by efficiently converting a given amount of biomass into a cooking gas, more households can meet their cooking demands than by burning the biomass directly, and detrimental health impacts are greatly reduced.

Two gases that can be made from biomass at small scale for cooking are “producer gas”, via a simple high-temperature process and biogas, via low temperature anaerobic fermentation. Producer gas generators are being installed today in many villages of Shandong Province, China, to convert corn stalks into cooking gas supplied

Table 8
Global market potential for electricity production from bagasse [54].

Country	Sugarcane production (tons/year)	Potential for electricity production (GWh/year)	Bagasse potential as percentage of electricity demand
Brazil	386,232,000	38,623	11.50
India	290,000,000	29,000	5.83
China	93,900,000	9390	0.72
Thailand	74,071,952	7407	8.15
Pakistan	52,055,800	5206	8.36
Mexico	45,126,500	4513	2.42
Colombia	36,600,000	3660	9.19
Australia	36,012,000	3601	1.95
Cuba	34,700,000	3470	25.93
USA	31,178,130	3118	0.09
Philippines	25,835,000	2584	6.16
Others	244,581,738	24,458	0.32
Total	1,350,293,120	135,029	0.97

to homes [50]. In Shandong, the amount of corn stalks required to provide a household with its daily cooking energy needs when the stalks are converted to producer gas is about half as large compared to that required when they are burned directly. In India, cattle dung is burned directly for cooking in many rural homes. In a few villages, dung is first converted into biogas by anaerobic digestion, producing valuable fertilizer as a by-product. Because of the high efficiency with which biogas can be used, some 20% less cattle dung is needed to meet the same cooking needs as with direct burning [51].

6.1.2. *Small enterprise applications*

In small industrial applications, rural enterprises are often seeking to modernize their use of biomass resources to improve their competitiveness. The more efficient use of locally available biomass energy resources—by brick-makers, bakers, ceramic and wood workers, timber-dryers, agricultural processors, and others—also contributes to increasing the sustainability of these important rural enterprises in many cases. For example, efficient down-draft pottery kilns have been developed in Mexico that help artisans to reduce fuel wood consumption, while simultaneously eliminating the use of lead and improving the competitiveness of rural pottery enterprises [52].

6.1.3. *Industrial applications*

Sugarcane provides an example of the potential for biomass modernization at large industrial scales. Over eighty developing countries grow and process sugarcane, generating substantial quantities of by-product biomass fiber (bagasse) that is used today at most mills as a fuel for combined heat and power (CHP) generation. CHP systems typically generate just enough electricity (a few megawatts at an average-sized facility) and process steam to run the mill. Because such an abundance of bagasse is generated, however, the CHP systems are designed to be inefficient in order to consume all of the bagasse and thereby avoid disposal problems. With more efficient CHP systems, sugar factories can generate substantial amounts of electricity in excess of their own needs. Fig. 1 shows the excess electricity generation possible per ton of cane processed with condensing-extraction steam turbines (CEST), a commercially established technology increasingly being considered for sugar mill application and with biomass-gasifier/gas turbine combined cycles demonstration today offers some perspective on the potential contribution of "cane power" to overall electricity supply in the future. For developing countries as whole, "excess" electricity (i.e., above and beyond that needed to run the sugar or ethanol factory) from cane residues could amount to 15–20% of the projected electricity generation from all sources in these countries in 2025 [13,53]. Fig. 1 shows electricity generated in excess of on-site needs per ton of sugarcane crushed at a sugar or ethanol factory using different cogeneration technologies. CEST is a condensing extraction steam turbine (steam pressure of about 60 bar). BIG/GTCC is a biomass-gasifier/gas turbine combined cycle. A typical milling season lasts about 6 months, during which time bagasse is available as a fuel. Sugarcane trash (tops and leaves), if collected, would enable electricity to be generated year-round, thereby enabling much greater quantities of electricity to be generated.

Pakistan is the fifth largest sugarcane producer in the world with a production of 47,244,100 million tons [14]. The government has allowed Pakistan Sugar Mills Association to cogenerate 2000 MW electric power by using bagasse as fuel [8]. Bagasse cogeneration describes the use of fibrous sugarcane waste—bagasse—to cogenerate heat and electricity at high efficiency in sugar mills. This indicates that there is abundant opportunity for the wider use of bagasse-based cogeneration in sugarcane-producing countries and to contribute substantially to high efficiency energy production. Yet this potential remains largely unexploited.

According to analysis undertaken by WADE, summarized in Table 8, the bagasse cogeneration can make substantial contributions to national power generation in several countries, including Brazil, India, Thailand, Mexico, Cuba, Pakistan, Colombia and the Philippines (the potential in China, in absolute terms, is also high, though a small fraction of that country's needs). These countries

Table 9
Comparison between traditional and modern bio-energy systems [55].

Characteristics of technology	Traditional	Modern
Fuel	Mostly gathered or collected and in some cases purchased	Commercially procured
Capital	Low capital cost	High capital cost
Labour	High labour intensity at household level in collection of fuel	Low labour intensity at household level but overall high labour intensity compared to other energy sources
Conversion process	Low efficiency and poor utilization of biomass	Higher efficiency and higher utilization of biomass
Energy uses	Energy for cooking and heating in poor households in developing countries	Commercial heating, electricity and transportation
Emission controls	Poor emission controls	Controlled emissions
Co-product	No co-products	Commercially useful co-products

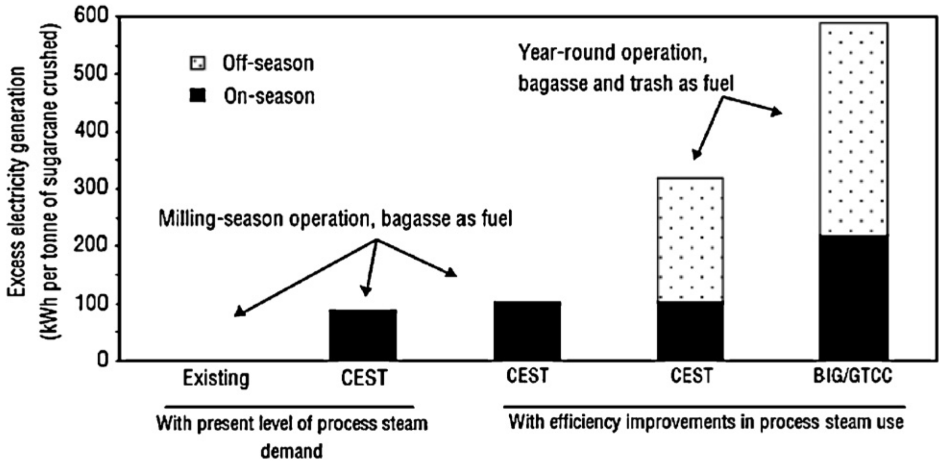

Fig. 1. Electricity generated in excess of on-site needs per ton of sugarcane crushed at a sugar or ethanol factory using different cogeneration technologies.

produce 70% of the world's sugarcane and, as an average, bagasse based cogeneration could satisfy over 7% of total national demand. WADE believes that no more than 15% of this potential has been effectively realized.

6.2. Modern bio-energy

Modern bio-energy is used mostly for the generation of electricity or transportation. Liquid biofuels for transportation such as ethanol and biodiesel are examples of the emerging energy alternatives.

Table 9 describes in detail the key differences between traditional and modern biomass in terms of input, output and conversion technology while Table 10 gives benefits associated with local bio-energy production. Traditional forms of biomass uses are characterized by low capital, low conversion efficiency, poor utilization of fuel, and poor emission controls whereas modern forms of biomass use are characterized by higher capital, higher conversion efficiency, better utilization of fuel, and better emission controls [55]. Transformation of low efficiency fuels to high efficiency convenient fuels involves substantial investments, and often the transformation process involves loss of energy.

6.2.1. R&D work on renewable energy recourses in Pakistan

Research and development work has been started to explore renewable energy products in Pakistan, but there is still a need for more serious and extensive research to promote the renewable energy technologies. Table 11 lists the government and private organizations involved in R&D on renewable energy recourses. These organizations have developed and promoted renewable energy products but most of them remained at modest level and were unable to go in large-scale production. Realizing the importance of biodiesel, AEDB outlined National Biodiesel Programme and decided to assist and facilitate the stakeholders involved for this purpose. AEDB formulated Policy Recommendations for use of Biodiesel as an Alternative Fuel which are primarily aimed at reducing the country's fuel import bill. The Economic Coordination Committee (ECC) of the Federal Cabinet has approved the Policy Recommendations for use of Biodiesel as an Alternative Fuel. In collaboration with AEDB, Pakistan State Oil Ltd. (PSO) has established a Jatropha Nursery and a Jatropha Model Farm at 22 acres land available at Pipri Marshalling Yard (PMY), Karachi. AEDB also provided a Biodiesel production plant to PSO for the optimization of biodiesel processing techniques. PSO has processed and tested different biodiesel blends on its fleet vehicles and generators. With the help of AEDB, Pakistan's first ever commercial biodiesel production facility has been setup in Karachi by M/s Eco-Friendly Fuels Private Ltd. This Biodiesel refinery has a capacity of producing 18,000 tons of biodiesel per annum [57].

In current scenario, when Pakistan is facing severe energy crisis, renewable energy sources, especially abundantly available biomass is gaining increased attention of researcher to search alternate solutions for energy scarcity in Pakistan.

6.2.2. Biomass power

Energy is an integral part of society and plays a critical role in its socio-economic development by raising the living standard. The state of economic development of any region can be evaluated from the pattern and consumption quality of its energy. As the economy grows, the energy demand increases and the consumption pattern varies with the source and availability of its energy, conversion loss and end use efficiency [14,58].

During different stages of development, societies have experimented with various sources of energy ranging from wood, coal, oil and petroleum to nuclear power. In recent years, public awareness and political concerns over environmental issues and energy security have led to the promotion of renewable energy resources. Biomass is one such resource that could play a significant role in a more diverse and sustainable energy mix. Bio-power, or biomass power, is the use of biomass to generate electricity. The energy obtained from biomass is a form of renewable energy and, in principle, utilization of this energy does not add "new" carbon dioxide, a major greenhouse gas, to the atmosphere, in contrast to fossil fuels. Biomass has been used as an energy source for thousands of years, ever since humans started burning wood to cook food or to keep them warm. As per an estimate, globally photosynthesis produces some 220 billion tons of dry biomass each year with 1% conversion efficiency [14,58,25,59–61].

6.2.3. Bio-power technologies

There are six major types of bio-power systems: direct-fired, co-firing, gasification, pyrolysis, anaerobic digestion and small, modular systems. Most of the bio-power plants use direct-fired systems. In addition, gas and liquid fuels can be produced from biomass through pyrolysis. In pyrolysis biomass is heated in the absence of oxygen. The biomass then turns into a liquid called pyrolysis oil, which burns like petroleum to generate electricity. Several bio-power technologies can be installed in small, modular systems which can generate electricity at a capacity of 5 MW or less [62]. Bridgwater et al. [60] presented a comparison of pyrolysis, gasification and direct combustion for electricity generation from wood chip feedstock and concluded that fast pyrolysis system has

Table 10
Benefits associated with local bioenergy production [56].

Dimension	Benefit	Dimension	Benefit
Social aspects	Increased standard of living Environment Health Education Social cohesion and stability Migration effects (mitigating rural depopulation) Regional development Rural diversification	Supply side	Increased productivity Enhanced competitiveness Labour and population mobility (induced effects) Improved infrastructure
Macrolevel	Security of supply/risk diversification Regional growth Reduced regional trade balance Export potential	Demand side	Employment Income and wealth creation Induced investment Support of related industries

Table 11
Organizations involved in R&D on renewable energy resources in Pakistan [11].

Government organizations	Universities and institutes		Private organizations	
1. Directorate of New and Renewable Energy, Ministry of Petroleum and Natural Resources	1. NED University of Engineering and Technology, Karachi	2. National University of Science and Technology (NUST), Rawalpindi	1. Techcorp Holding, Inc., Islamabad	2. Siemens Solar, Lahore
2. Alternative Energy Development Board, Ministry of Water and Power Government of Pakistan			3. Grid Solar, Karachi	4. Solar Products Incorporated Pakistan, Quetta
	3. University of Engineering and Technology (UET), Peshawar	4. University of Engineering Technology (UET), Lahore	5. Solargy, Karachi	6. FINATRA Alten, Karachi
3. National Commission for Alternative Energy (NCAE)			7. Soltec International, Bahawalpur.	8. Energen, Karachi
	5. BZ University, Multan	6. University of Karachi, Karachi	9. MerinAgroTools	10. Wind Baron, Rawalpindi
4. Solar Energy Research Center (PCSIR)	7. ShaheedZulfiqar Ali Bhutto Institute of Science and Technology (SZABIST), Karachi	8. COMSATS Institute of Information Technology (CIIT), Lahore	11. Economia, Islamabad	12. Volta Batteries, Hattar
			13. Firex Solar, Islamabad.	14. Alternate Energy Group, Advanced Engineering Research Organization, Wah
			15. Trillium Pakistan, Rawalpindi	
			16. Sun power Systems, Karachi	17. Hagler Bailey, Islamabad
5. Pakistan Council for Renewable Energy Technology	9. Agriculture University, Faisalabad	10. University of Balochistan, Quetta	18. Sahgal Electronics, Rawalpindi	19. Sunpack, Faisalabad

great potential to generate electricity at a profit in the long term, and at a lower cost than any other biomass to electricity system at small scale. A lot of studies have been made by researchers for the environmental and economic feasibilities of RE from biomass for different countries. Recently, Buragohain et al. [63] highlighted the technical and economical issues related to decentralized power generation in India using biomass gasification and present their analysis for both fixed bed and fluidized bed gasification with pre- and post-process treatment. The study suggests that the downdraft gasifier design, being well developed and demonstrated, is the most feasible technology for wood biomass to energy conversion [61]. Formerly Lora and Andrade [64] demonstrated available technologies for electricity generation out of biomass for different power ranges and concluded that biomass energy technologies having the high and medium technological maturity and economic feasibility are the steam cycle, gasification with internal combustion and stirling engine and biodiesel/internal combustion engines. For small power systems (5–200 kW) the situation is critical as they are not available technologies with high technological maturity and economical feasibility. Extensive research is still needed to find optimal biomass to energy conversion flow sheet with minimum waste generation and valuable by-products.

From the present plans of governments in Asian countries, it is foreseeable that large amount of land, water and man-power resources will be devoted to bioenergy programs. Pakistan government also has initiated projects on biomass energy. Currently, A-Power Energy Generation Systems, Ltd., a leading provider of distributed power generation ("DG") systems in China and a fast-growing manufacturer of wind turbines, and Shenyang Power Group ("SPG"), a subsidiary of A-Power, have signed agreements with Pakistan Amraas International Private Limited ("Amraas") on two separate DG projects in Pakistan [65]. The first project entails the construction and operation of two 25 MW biomass power plants for Amraas. The total value of the contract is estimated to be

$120 million (RMB 816 million). Construction is scheduled to commence in 2010–2011. The second project concerns a geothermal project for the Pakistan Parliament Building (753,480 square feet) between SPG and Amraas International. SPG will act as the general contractor for the engineering, procurement and construction and equipment adjustment for the project, and will subcontract certain portions of the project to third parties. The Pakistan government is expected to provide the funding for the project. In December 2009, AEDB has issued a letter of intent to SSJD, a local company, which is working on alternative energy projects, for construction of another biomass power plant, which will use agricultural waste to produce 12 MW.

Available biomasses to power conversion technologies are equally applicable for all types of feedstock. There have also been many studies performed in recent decades to estimate the future demand and supply of biopower. Overall, the world's bioenergy potential seems to be large enough to meet the global energy demand in 2050 [66]. Shifting the energy mix from fossil fuels to renewables can now in most cases be done using best practices and existing technologies. However, the shift in the energy mix requires much more investment in infrastructure, equipment and in R&D in case of biomass feedstock available in Pakistan. Moreover, a prerequisite for achieving bioenergy's substantially, high potential in all regions is replacing current inefficient and low-intensive management systems with best practices and technologies.

7. Conclusion

Because Pakistan is an energy-deficient country, indigenous energy sources of Pakistan are strategically important. While renewable energy sources have made great contributions to Pakistan's energy supply mix, there is a need for more research and development on renewable energies to increase their efficient utilization. While proven benefits on social aspects and macrolevel are associated with local bioenergy production, the future supply of biomass energy depends on energy prices and technical progress, both of which are driven by energy policy priorities. With efficient use of biomass in producing energy, Pakistan can meet a variety of energy needs, including generating electricity, heating homes, fueling vehicles and providing process heat for industrial facilities, but there is still a need for more serious and extensive research to promote the renewable energy technologies. The shift in the energy mix also requires much more investment in infrastructure, equipment and in R&D in case of biomass feedstock available in Pakistan.

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